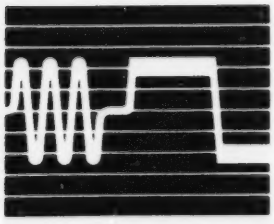
TP 4840 E

Application of Fibre Optics to Marine Transportation

Prepared for the
Transport Canada
Transport Development Centre

By
Seimac Limited



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APPLICATION OF FIBRE OPTICS

To

MARINE TRANSPORTATION

by

Dr. B.E. Paton

Focal Marine Limited

for

Seimac Limited

1378 Bedford Highway

Bedford, N.S.

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17. Abstract

Recent marine installations of fibre optic systems have been highly successful and reliable. The change-over to fibre optics systems by the telecommunications industry will result in a substantial price reduction. Systems currently not cost-effective will soon become so. Very comprehensive world and national standards are expected by the end of 1983. Second sourcing, a lack of which has plagued the industry, will then be assured. For ship safety, fibre optics is most attractive. Spark hazards, electromagnetic interference and ground loops, all problems with electrical cables, are non-existent with fibre optic cables. New standards for cables and installation practices may be warranted in several areas unique to marine transportation. Sea going trials on board a Canadian Coast Guard vessel are recommended as a test ground for Canadian standards and reliability studies.

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17. Résumé

Des systèmes de fibres optiques récemment utilisés sur des installations marines ont eu beaucoup de succès et ont prouvé être fiables. La conversion aux fibres optiques dans le secteur des télécommunications apportera des économies substantielles. Des systèmes qui sont présentement peu rentables le deviendront sous peu. Vers la fin de 1983, des normes nationales et internationales devraient être établies. Ceci stimulera l'établissement de nouvelles sources d'approvisionnement. En ce qui concerne la sécurité maritime, les systèmes de fibres optiques sont très attrayants. Les risques d'étincelles, l'interférence électromagnétique et les courants de sol, problèmes associés aux systèmes conventionnels de fils électriques, ne sont pas présents dans les systèmes de fibres optiques. De nouvelles normes pour les câbles et les méthodes d'installation devront être établies spécifiquement pour le transport maritime. Des essais en mer à bord de navires de la Garde côtière sont recommandés pour établir des normes canadiennes et pour faire des études de rendement et de fiabilité.

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SUMMARY

This report was undertaken to examine certain aspects of the use of fibre optic technology in marine transportation.

A number of recent installations of fibre optic cabling in large vessels has shown that the technology is now moving from the laboratory into practice. Although many of these new installations have been in military vessels, it is likely only the depressed state of the ship-building industry has kept the number of civilian vessel installations to a modest figure. The benefits of using fibre cables in vessels are similar to those found on land; large bandwidth, high error-free data rates and immunity to electromagnetic noise. In addition, it seems apparent that the use of fibres can substantially reduce top-weight and, as the technology matures, provide substantial cost saving in material and installation. It is likely that fibre performance in fire and flooding situations will also prove to be a significant advantage.

There are no known non-military shipboard standards for fibre cables, components or installations. The United States Navy will have a comprehensive set of standards within weeks. Testing procedures which would be applicable in part are now being formulated for the civilian sector and industry standards are becoming more common and reliable. IEC and EIA standards should be in print by 1984 and some aspects of these will find use in marine work.

Since there are no standards for fibres to parallel IEEE-45 for copper cables, there are no known "approved" cables. Cables used to date have been communications cables developed for rigorous environments.

Within the Canadian Coast Guard there would appear to be two potential areas of application; fibre cables could be used in the Polar Class icebreakers to carry data in the high noise environment of thyristor controlled main motor rooms and fibre cables could be used in communication systems. Both applications constitute valid areas for installation and investigation. Within the marine industry itself the most likely technical aspect leading to the use of fibres will be in the carrying of digital control signals in a high noise environment. Improving cost advantages and top-weight considerations could set a trend to a more general copper replacement for all control and communication cables.

The main technical factors which must be addressed before fibre cables become standard are those of cable

construction for the harsh environment, installation practices and the absence of skilled manpower. Reliable bulkhead glands and connectors must also be developed. The electro-optical design of cables and terminal devices is well in hand.

This report recommends some specific studies in the area of cable behavior such as ice crush, inflammability and salt water penetration. Sea trialsto investigate installation practices are recommended. These trials, ashore and afloat, should parallel and be part of initiatives by Transport Canada to obtain mutually agreed standards between national authorities and classification societies.

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1. INTRODUCTION

1.1 General

Fibre optic technology is on the verge of revolutionizing land-based communication systems; digital telephone, fascimile, picture phones, high speed computer links and CATV services using fibre are now within reach. The great demand for fibre, connectors and components will bring the cost downsubstantially. Today, optic fibre cable is as inexpensive as copper cables; tomorrow, optic fibre will be the chosen communication media. Spin-off from land based systems will make it economical to install similar systems in the marine environment; ships, rigs and platforms. Transport Canada has the responsibility to ensure that this technology is transferred to the Canadian marine sector in an orderly and safety conscious manner. Ship automation, multi-point fire and damage control systems, high speed data links, all concepts for the future, will become tomorrow's realities and the industry will need guidance.

1.2 Project Objectives

The general objective, as set out in the contract documents, is to report on the contribution fibre optic technology could make towards improving marine transporation efficiency and safety. This includes:

a. review of the state-of-the-art as it applies to shipboard applications and installations.

b. review of specifications for shipboard installation, testing and checkout procedures of fibre optic systems.

c. comments on existing test procedures and identify any new ones specific to fibre optic technology.

d. identification of potential applications for fibre optics within Transport Canada marine needs.

e. recommendations for future Transport Canada studies.

1.3 Terms of Reference

Detailed Work Statement

a. Investigate and report on the state-of-the-art in fibre optic technology as it relates to shipboard applications. Identify the expected benefits and costs of fibre optics compared with conventional shipboard wiring techniques.

b. Review existing regulations and specifications for the installation of fibre optics in a shipboard environment.

c. Identify and appraise existing testing procedures for fibre cables which may be applicable to shipboard equivalents.

d. Identify existing fibre cables which are currently suitable for shipboard installation.

e. Study potential Coast Guard applications for fibre optic systems onboard ships. Also examine other potential applications of this technology by the Canadian marine industry.

f. Outline the technical factors which must be addressed to ensure that fibre optics technology will meet the demanding requirements of the marine transportation industry.

g. Prepare recommendations for fibre cable tests or trials either ashore or in appropriate vessels to further evaluate the potential of this technology.

1.4 Report Content

This report reviews the present state-of-the-art of fibre optic technology as it relates to marine transport. Section 2 of this report describes the methodology used to carry out the project. Section 3 reviews current installations of fibre optic systems. Section 4 reviews the merits and shortcomings together with expected benefits and costs of fibre optic systems as it applies to marine transportation. Current standards, installation and checkout procedures are reviewed in Section 5 while Section 6 discussed the implication of fibre optic technology on ship safety. Section 7 lists the opportunities for the marine industry in this new field. Conclusions and recommendations are presented in Section 8.

2. PROJECT METHODOLOGY

This section describes the type of work carried out to meet the project objectives. These objectives (listed in section 1.2) fall into three basic categories.

i) Information Collection on Shipboard Installation, State-of-the-Art, Standards & Procedures.

Work Included:

a) Scrutiny of published papers
b) Scrutiny of published standards
c) Scrutiny of trade journals
d) Visit to Electronics Industries Association, EIA office, Washington, DC
e) Establish contacts with US manufacturers and government personnel
f) Visits to Canadian manufacturers in the Ottawa area
g) Conversations with the authorities listed in Appendix A.

ii) Analysis and Assessment of Information

Work included:

a) Detailed analysis of information
b) Procurement of relevant documents
c) Further conversations with selected persons
d) Visits to ocean vessels

iii) Recommendations

Work Included:

a) Discussion with International Electrotechnical Commission, IEC Standards community members
b) Discussion with Naval Architects
c) Report writing

3. REVIEW OF MARINE INSTALLATIONS OF FIBRE OPTIC SYSTEMS

3.1 Container Vessel America Maru

The installation of a fibre optic engine control system between the bridge and engine room of the cargo vessel America Maru, Mitsui OSK Lines, has been heralded as the first commercial fibre optic transmission system installed on a vessel in regular marine use (1). Mitsui Engineering and Shipbuilding Co. Ltd. teamed up with Fujikura Cable Works, Ltd. to design and install this pioneering system.

Japanese engineers have always been quick to pick up on new technology and use it in innovative applications. Recognizing the many advantages of optical fibre transmission, proven in land installations, various engineering prototypes were built and tested. These systems indicated fibre optics were reliable enough to justify a marine application. The fibre optic system installed links computers on the bridge with numerous test points and sensors in the engine room to provide real time data for engine control. This is not just an experiment on reliability of fibre optic systems but a test of shipboard automation.

In designing the system, the greatest consideration was given to the cable construction. The cable had to be installed in a limited space and would have to withstand the mechanical working prevalent in normal ship cables; namely vibration, tension, compression, snap loading and bending. A multiple steel braided armor cable was adopted which contained both optical fibre and copper conductors. This cable provided excellent durability against external physical forces and enabled the many advantages of optical fibres to be exploited.

Reported Characteristics of Fibre Optic Transmission System Installed in the America Maru are:

i) Low loss fibres with wide bandwidth lend themselves to high speed data transmissions and dense multiplexing of signals.

ii) Optical fibres are entirely free of inductive noises, hence reliability of transmission systems was improved remarkably.

iii) Non-inductive and non-conducting properties permitted the installation of these cables next to large power carrying cables.

iv) Excellent resistance to vibration

In summary, optical fibres have proven reliability, so they may be used even in critical control applications.

3.2 Naval Installations

Although the American Maru was the first commercial application of fibre-optics in marine transportation in the naval world, similar installations have been installed, tested and tried over the last 10 years. Foremost in these activities has been the US Navy .

Examples

- A fibre optic telephone system in the USS Little Rock has operated for six years without failure.(2)
- Experimental CCTV system in the USS Kitty Hawk (aircraft carrier) uses wideband FM transmission in fibre cable.(2)
- Fibre optic implementation of the US Navy's Information Transfer System (ITS) by Rockwell's Marine systems division
- Litton/Raytheon radar links
- Nuclear submarine data links
- Towed arrays and sonar cables

As far back as 1976, the Canadian Navy instituted a feasibility and engineering prototype study of a 35 channel shipboard communication system (3). It was to simulate the complete fire and damage control system and voice communications of a DDH-280 class destroyer. It was installed at Halifax's Fleet School where it sucessfully met the specifications. Involved in this project was Communications Research Centre(Ottawa), Bell Northern and Litton Industries.

The US Navy has supported many recent developments. The FOSS program (Fibre Optic Sensor Systems) has developed many fibre optic sensors including hydrophones, level, flow, temperature, pressure, and position encoders. Many are close to commercial realization. These devices offer reliability, no spark hazard and are suitable for explosive, wet or electrically noisy environments.

The likely marine applications of these sensors will be fire and flood control, temperature sensing, monitoring of engines, turbine blades, oil levels, bearing

wear, gas and steam control, vibration,low level alarms, shaft encoders for propellers, pitch control, hydraulic pressure levels, alarms, exhaust gas temperatures and lubricating oil pressures.

While the US Navy has no standard shipboard fibre optics installations, (they are all "one-of" designs), they have encouraged manufacturers to produce systems with "drop-in" fibre optic links. These systems, developed by Litton, Sperry,and Raytheon, are or will be found in radar, communications, fire and damage control and weapons systems. To further this goal the US Navy is now developing a comprehensive set of standards (see chapter 5) for the shipboard installation and check out procedures of fibre optic cable.

Here in Canada, the Navy has funded a feasibility study and engineering model for a fibre optic implementation of a Shipboard Integrated Processor and Display System (SHINPADS)* (4). Although SHINPADS* is to provide communication and control to 256 data ports, at 10 Megahertz rates, the optical fibre version uses only 32 passive ports. The companies contributing to these programs included Sperry/ Univac and Canstar.

3.3 Undersea Installations

The Oceangraphic sciences have been most aggressive in applying new technology. Here, the wide bandwidth of fibre optics is exploited to maximize data collection in the time available on station.

The Applied Physics Laboratory of the University of Washington is using a fibre optic tether to bring back temperature data from a free fall sensor system to the ship's laboratory (5). Valuable information on the ocean's thermoclines and the operation of a fibre optic cable in the ocean was gained.

The Bedford Institute of Oceanography expects data rates for scientific data collection to get higher and higher. Since there is no reason to think that ships will become less electrically noisy, fibre optic cable will be a must for new vessels. A fibre optic instrument network for a glass reinforced plastic survey launch is planned.

*SHINPADS is a registered trademark of the Canadian Department of National Defence.

It is most expensive both in cost and in lives to put humans in undersea locations. The offshore oil industry has encouraged the use of undersea unmanned tethered vehicles. These systems sometimes require large data rates and use television monitoring. A wide bandwidth is necessary to retrieve all these signals. MARCUS, a Japanese unmanned submersible operating in depths up to 200 metres, uses a fibre optic umbilical cable in its role as a submarine cable inspector (6). Other similar type vessels are used for offshore oil pipe inspection.

The Canadian Department of Fisheries and Oceans has ordered a fibre optic data link for a bottom referencing underwater towed instrumentation vehicle (BRUTIV)(7). The single fibre will transmit a video channel, an audio channel, 16 analog data signals and 32 digital monitoring points to the surface vessel and send 3 analog control signals plus 32 command channels to the underwater vessel simultaneously.

As far back as 1976, a prototype diver umbilical cable (8) in England carried information on diver life support systems. Heart rate, blood pressure, diver core temperature and gas pressure were measured at the diver site and transmitted to the surface vessel over an optic fibre.

3.4 Other Marine Installations

International Marine Radio Co. (England) and VAF Instruments (Netherlands) have exploited the non-existent spark hazard of fibre-optics to connect instrumentation in the engine room with the hazardous space of the pump room of commercial tankers(9). Information on ballast discharge is carried via optical fibres to a safe area. The fibre optics have proved entirely successful and data is available from hundreds of installations.

The National Maritime Institute (England) has been using optical fibres bonded to offshore structures to indicate critical fracture strains(10). The basis of the technique is that the light path will be interrupted or broken at the bonded point if a plastic strain or crack opening occurs in the structure. These devices, a form of fibre optics strain gauge, can be placed at difficult to access points, such as ship keels,cargo tanks or support structures of offshore drilling platforms.

The RV Polar Star (German) uses a fibre optic cable to interconnect the various scientific computers. This system, installed by Honeywell, is a standard office system and no special effort has been made to produce a marine version.

Electro- Flow Controls Inc., supplier of off-shore oil

instrumentation, uses optical data links to interconnect instrumentation packages on the rig floor to a central control room.

3.5 Summary

There have been many successful commercial applications of fibre optic systems in marine transportation.

The numerous advantages of optical fibres,

- no spark hazard
- no ground loops
- EMI, RFI or EMP immunity
- small size
- impervious to moisture and water,

are just too attractive not to be considered by naval architects and designers.

One might question why, if fibres are so good, are there not more installations? The answer is likely found in the current recession, and lack of shipbuilding.

Quoting Robert Martinet, Vice President, FIBERCOM,

"There are few shipboard installations but certainly a great number on the drawing board".

Again quoting Stewart Grossman, from M. Rosenboltt & Son (Naval Architects and Marine Engineers)

"little is happening today except in the U.S. Navy. There is lots on the drawing board but no one is building."

4. CHARACTERISTICS OF FIBRE OPTIC SYSTEMS

This section is not intended to be a comprehensive review of fibre optic technology. A basic study including definitions, terminology and manufacturers list is contained in Transport Canada report TP 2481 entitled: Use of Fibre Optics in Transport Canada Communications.

4.1 Review of Fibre Optic Technology as Applied to Marine Systems.

Reduction in crew size and the coincident increase in shipboard automation has led to a large increase in the amount of electrical and electronic equipment on modern vessels. This proliferation of electronic equipment places a premium on the space required for the large volume of cables. Equipment and cable fitted into increasingly cramped spaces cause additional problems with electro-magnetic interference. Interference from radios, radar, electrical machinery, lighting, electro magnetic pulse, etc. can cause significant degradation in system performance and even damage terminal equipment in systems using electrical cables. Mr. D. Gray, has discussed in detail the increased risk of electromagnetic interference in new vessel designs (11). He sites one example where a large cruise ship experienced interference problems with bridge instruments caused by a thyristor-operated dimmer switch two decks below. In the new CCG polar ice breakers, extensive use of thyristor controlled circuitry is planned.

New electronic instrumentation in ships tends to operate at lower signal levels. This, coupled with new vessel design, which locates accommodation and machinery in the aft section, places great congestion on electric equipment, power cables, radio and navigation instruments. Associated with shipboard installation of electric cable are problems of electro-magnetic compatibility, watertight integrity, hazards from short circuits and in military vessels, transmission security.

An optical fibre consists of a very small glass rod approximately 100 microns diameter (about the size of a human hair). Light directed on one end of the fibre emerges at the other end with a very small loss of signal. Modern optical fibres have losses of less than 2dB/km and smaller losses can be expected using long wavelength sources. In the telecommunication field, minimum loss translates to larger spacing between transmitter and receivers. The current record is 54 kilometres. In ships, low loss translates into larger signal to noise ratios hence greater data reliability.

The fibres are coated with a thin layer of buffering material which reduces losses and improves strength and flexibility. The fibres are then covered with a flexible jacket, usually HYTREL, to add further protection against strains and to ensure fibres are not bent beyond their guaranteed bend radius. KEVLAR strength members, soft plastic flame retardant jackets, metallic foils or armor are typical outside jacketing. This basic structure (Fig. 1) can be incorporated with other cables to produce more complex cables (Fig. 2).

Optical fibres transmit information via light pulses rather than electron pulses. The usual impedance characteristics which limit the frequency response of copper cables do not apply. The absoutely flat bandwidth of optical fibres up to many gighertz is compared to that of twisted pairs in Fig. 3 or coaxial cable in Fig.4. This feature explains the attractiveness of optical cables for high density data links.

4.2 Merits of Fibre Optic Systems with Respect to Ocean Applications

Optical fibres are totally dielectric (nonconducting), hence data can be transmitted directly across very high potentials without need for isolation transformers. Glass provides total isolation hence cross-talk, radio frequency interference and electromagnetic interference are eliminated. Ground loops inherent with coaxial cables are totally eliminated with fibre optics. Electronic isolation afforded by fibre optics permits independent design of transmitters and receivers. Being dielectric, fibres do not attract lightning nor act as an antenna. Lightning, radar signals, inductive fields, high current machines, thyristor controls,etc. have no effect on optical transmission. In addition, fibres do not radiate any signals therefore they do not add any interference. Optical fibres cannot spark or short circuit hence they can be used in hazardous environments. Elimination of short or open circuit hazards found in electrical cabling permits fibre optic cable to be routed through combustible materials, explosive or hazardous areas.

A comparison of optical fibres with twisted pairs and coaxial cables is contained in Table 1.

Property	Twisted	Coaxial	Fiber Optic
Immunity to RFI*	N	N	Y
Immunity to EMI*	N	N	Y
Immunity to EMP*	N	N	Y
Total Electrical Isolation	N	N	Y
Transmission Security	N	N	Y
Cross Talk	Y	Y	N
Spark/Fire Hazard	Y	Y	N
Short Circuit Loading	Y	Y	N
Temperature Limits	300	300	1000
Installation Factors	difficult	complex	simple
Cost Trends	increasing	increasing	decreasing

*Radio Frequency Interference *Electro-magnetic Interference
*Electro-magnetic Pulse

Table 1 Comparison of Copper Versus Fibre Optic Cables

Another significant benefit of fibre for shipboard installations is low weight and small size. A modern destroyer requires 150 miles of copper cable, with 75 percent of this used for information transfer. Use of fibre optic cable would significantly reduce the space requirements and reduce top weight by several tons. In a feasibility study for aircraft carrier radar, 47 cables carrying 375 separate signal lines were replaced by a single fibre-optic cable containing only 7 fibres (12). The fibre optic cable weighed 15 pounds,while the copper cables seven tons. On a submarine sonar link, an impressive 80 to 1 weight savings over shielded twisted pair cables was achieved. Although military examples tend to be more dramatic the same ratios are applicable to commercial vessels.

Optical cables for data transfer links have smaller diameter and are lighter than conventional cables so they can often be pulled through existing ducts. The cable design ensures the cables can withstand the tension loads on pulling. Optical fibre can often be pulled with forces 3 to 4 times as large as copper cable. Fibre optic cable can be pulled in longer runs because the frictional forces are proportional to the cable weight and glass is 1/6 as dense as copper. For example, a coaxial cable having the same diameter as an optical cable weighs four times as much.

While it is often the large bandwidth of optical fibre which is cited as the most important factor, in marine transport we may find the atttributes of weight, size and radio frequency interference to be more important.

4.3 Shortcomings of Fibre Optic Systems In Marine Applications

Shortcomings of fibre optics are,

i) systems require multiplexing to exploit the large bandwidth of the fibre.
ii) while the cost of fibre vs copper is competitive the associated electronics are expensive.
iii) fibres cannot support D.C. current which is needed at repeater or data ports.
iv) large and un-regulated proliferation of manufacturers makes second sourcing difficult.

In order to exploit the gigahertz bandwidth of fiber optic systems, signals must be multiplexed. In the case of the aircraft carrier, mentioned in Section 4.2, the 375 signals consisted of 27 analog video signals, 101 timing pulses and 247 level control signals. These were multiplexed into 7 fibre optic signals.

Cost comparisons should not be made simply on cable price per metre, but should include other factors such as the nature of couplers, opto-electric converters, splicing, terminating, available space and installation costs. It is difficult to make comparisons, but a few general comments can be made.

Optical fibres today are cost competitive with copper cable. The growing demand in the telecommunication field for optical fibre will bring the cost down further(Fig. 5). Copper is a limited and stategic material. Its cost will continue to escalate. The cost of cabling a single strand of copper versus a single strand of fibre is comparable. Fibre cable is smaller and lighter, hence pulling costs will be less.

It costs between $75 and $135 per meter to install a cable on board a ship.* Cable routing is dictated by space requirements, resulting in cable crowding, spaghetti routing and additional electrical interference problems. Fibre cables being smaller and lighter can be routed more easily with no regard for electrical interference. Independent of the bandwidth used, fiber optic cable should be less expensive to install. When the bandwidth is exploited, then the saving can be large. In the aircraft carrier radar cables example, the fibre optic cable cost $30,000 to install, while the copper cables cost $1,000,000; a ratio of 30:1.

*MALCOME MARTYPE, FERGUSON INDUSTRY, private communication.

A life cycle/economic study, part of the A-7 aloft program, that considered tradeoffs involved in using fibre optic systems as against twisted-pair wire and coaxial counterparts, found optical-fibre bulkhead and cable connectors are not only half the cost of equivalent coaxial terminations, but the assembly time of fibre optic cable and connectors takes 30% less than coaxial components (13).

A recent cost comparison (table II) for the conversion of an existing shipboard signal network aboard a US naval frigate with an equivalent fibre optic network shows a 90% reduction in cable volume and weight and a 78% saving in the cable and installation costs. This cost estimate was based on a one-for-one replacement of copper cables. One wire or switch is replaced by one optical fibre or fibre switch. This constraint gives a maximum advantage to copper wire.

Item	Copper	Fibre	Savings	%Savings
Weight (Lbs.)	592.4	50.40	542	92%
Volume (Cu.ft.)	13.32	0.92	12.4	93%
# of Cables	76	15	61	78%
Cable Length (ft.)	3975	840	3135	79%
Material Cost $	2025	1772	$253	12%
Installation Cost $	$139,125	$29,400	$109,725	78.87%
TOTAL COST $	$141,150	$31,172	$109,978	72.92%

Table II Cost savings for a fibre optic implementation of signal network aboard a naval frigate (14).

With electronic multiplexing and switching, the immense signal bandwidth of the fibre is exploited and the factors 300-3000% reported in previous are appropriate.

Optical fibres do not support DC current hence all data ports or repeaters must receive DC power from a local source. In the case of the "America Maru", the shipboard cable carried both fibres and copper power lines.

Naval architects and shipbuilders have traditionally been most conservative in employing new technology. As stated by one industry spokesmen, "We are designing ships

with a life expectancy of 20 to 30 years. We can not afford to use new technology if it might fail after 5 years". Although fibre optic systems have not been around for 30 years, systems in the U.S. Navy are working with high reliability 10 years after installation.

Perhaps the most pressing problem is second sourcing. Again, if shipbuilders can not procure components and replacement parts for the lifetime of the vessel, then they will not use them.

4.4 Areas of Concern

There are three additional areas of concern requiring further discussion.

These are

a. Connectors
b. Water integrity
c. Ice crush
d. Cable topology

Connectors: Fibre optic cables must be connected together or to terminal transmitters/receivers with connectors. While fusion splices* are attractive, the cost of installation and equipment do not warrant general usage on board ship. Mechanical connectors (similar to BNC type) are easy to install, terminate and maintain. Compared to installing a coaxial cable connector, fibre optic connectors are simple. However the required skills are new and different. Training of shipbuilding personnel in installation procedures is essential. One contractor was more than willing to talk about fibre optic installation, but was quick to point out, "Our people do not have the skills and must be trained. Who will pay?"

Water integrity: Many marine applications require penetration into watertight compartments. To preserve watertight integrity copper cable is usually routed into these areas within a gland or stuffing tube. Fibre optic cable must be protected from tensile loads, hence new techniques may be required for fibre optic gland seals. There are several promising approaches to this problem. Bell Labs have a new blocking material which seals but does not flow easily. In addition,the Naval Electronics Laboratory has developed some prototype bulkhead connectors.

* melting of optical fibre together to form a continuous link.

Ice Crush: In the Canadian climate, freezing temperatures are inevitable. While fibres, cables and components can be designed to withstand our climate, water penetration into the cable for one reason or another poses a problem. Water on freezing expands, bending the fibre in a random way. Each bend causes a loss of light. A bend over a 10 micron step causes a loss up to 0.3 dB. Many bends in a frozen water filled cable will make the system non-operational.

Cable Topology: If the wide bandwidth of the fibre optic cable is to be exploited in marine applications, then all communication and control signals could find themselves in one fibre optic cable. This signal centralization could have a major impact on vessel safety. Without cable redundancy, the entire ships operation could depend on one single strand of glass. New vessels will have to be designed with 2 or 3 redundant signal channels passing through different parts of the vessel. Due to the large potential savings with a multiplexed fibre optic system, the added cost of redundancy will have little effect on the overall cost saving analysis.

4.5 Future Trends

Telecommunication requirements are currently driving the industry. A total commitment by the telephone industry, would trigger a tenfold shift downward in cost of fibres. It is now policy, both internationally and nationally, to use fibre optic system in all new long haul operations Attenuation losses of less than 2dB/KM are common in the industry. Newer systems are moving to longer wavelengths 900 - 1100 nanometers where the attenuation is less than 1dB/km.

Fibre optic sensors will become more prevalent and find applications in many novel places.

Anticipated standards for the IEC, IEEE and JIS should clarify the terminology, measurements and definitions. The expected "shakeout" in the industry will develop standard product lines with second sources.

5. STANDARDS, INSTALLATION AND CHECKOUT PROCEDURES

5.1 Role of Standards

As with any new emerging technology, there is a great proliferation of devices, techniques, components, etc. This type of expansion further encourages growth, but can become a nightmare to designers and contractors who must design ships with a life cycle of twenty to thirty years. In many cases, the only compatibility is within a manufacturers product line.

In addition to components, the terminology and measurement techniques need to be defined. For example, consider the measurement of the core diameter of an optical fibre. Glass fibres consist of a central glass core approximately 50 microns in diameter surrounded by a glass or plastic cladding. Light is internally reflected at the boundary between the core, and the cladding. In order to connect fibres, and accurately predict system losses, the diameter of the fibre core is critical.

The end view (Fig. 6) of the same optical fibre photographed in two different test modes shows that the core diameter is significantly different between measurements techniques (15). Test procedure must be well defined to determine consistent measurements.

The US Department of Defence's goal is to have working standards available in the early eighties. Fibre optics have matured to the point where comprehensive standards (see section 5.3) are available, measurements can be believed (16) and some fibre optic connectors have met MIL-standard qualification (17). The National Bureau of Standards claims as of 1982 complete confidence in manufacturers' published specifications.

5.2 Current Canadian and International Standards

An extensive survey of commercial shipbuilders and marine interests (Appendix B) indicated there are few fibre optic installations and no working standards. Two American military contractors, Ingalls Shipbuilding and Newport News Shipbuilding have had direct experience with fibre optic ocean systems, but this work is mostly classified.

The primary working documents presently used are:

a. Military Standards DOD-STD-1678
   Fibre Optics Test Methods and Instrumentation

b. Military Specifications DOD-C-85045
Cables, Fibre Optics, General Specification

c. Electronic Industries Association (EIA) RS 455
Test Methods

d. International Electrotechnical Commission IEC 46E
Cables, Wires and Wave-guides

The most comprehensive document is DOD-STD-1678. It covers all aspects of fibre optic technology (Appendix C) and involved all US military services in its writing. Parts of its preparation have been sub-contracted to American Industry and hence many current components meet this standard.

The EIA RS-455-XX generic documentation is most complete, numbering 119 test procedures, although only 31 subsections are published, a complete list and subsection status is listed in Appendix D.

Current IEC documentation is most sketchy but an extensive draft of the new standards (Appendix E) is expected shortly.

While the Appendix D documents will be most useful, they are neither, complete, up-to-date, nor specific to the commercial marine industry. Fibre optic data links can be divided into functional elements such as cable, connectors, transmitters,receivers, terminal electronics and installations practices. Only two of these areas, fibre optic cable and connectors, have any substantive documentation.

While few comprehensive standards are publically available, there is a great deal of world activity presently developing new standards. These include

a. International Electrotechnicial Commission (IEC)
b. US Military TRI-Service Working Group (DESC)
c. Electronic Industry Association (EIA)
d. Japanese Industry Standards Association (JIS)
e. US National Bureau of Standards (NBS)

The documents which address ship board installation of electrical cable include:

a. Ship Safety Electrical Standards, TP 127, Transport Canada
b. Recommended Practice for Electric Installations on Shipboard, STD 45-1977, The Institute of Electrical and Electronic Engineers
c. Electrical Installation in Ships 92-1, International Electrotechnical Commission

5.3 Proposed Standards

At the time of writing, there is great activity both in the world and in national communities (noteably the US and Japan) in completing fibre optic standards by the end of this year, 1983.

The International Electrotechnical Committee, has circulated a working draft among member nations. Resulting from a four year study by subcommittee, SC46E, (fibre optics part of the technical committee, TC46, on wire and cable) the working draft is to be submitted for approval, on October 17, 1983 in Tokyo.

Since US industry supports the IEC working groups, there is a substantial effort in the EIA to complete the RS-455 specification by the Tokyo meeting. Japanese Industrial Standards (JIS) for optical fibres are expected to be published similarily before the end of the year.

The US military has just released a new standard (MIL-STD-188-111) on "Subsystem Design and Engineering Standards for Common Long Haul and Tactical Fibre Optic Communications".

The US Navy working hand in hand with American ship builders, has developed several very comprehensive manuals for shipboard installations of fibre optic cable and components.

They are:

a. Fibre Optic Checkout Procedures for Shipboard Installation, 60GP-N002
b. System Design Guide: Applying Fibre Optic Technology to Shipboard Systems 60GP-N004
c. Fibre Optic Cable Installation Procedures 60015-N007

These documents have been approved and are expected to be released by US Navy on October 31, 1983.

In addition, component specifications for,

Coupler, FO Cable, Passive Splitters	6060-N010
Coupler Inserts	6060-N013
Sources	6030-N001
Detectors	6030-N002
Cable Specifications	6015-N002
Connectors	6060-N002
Hull Penetrators	6060-N011
Pressure Harness	6020-N001
Bulk Head Penetrator	6060-N012

have been released in preliminary draft form.

5.4 Recommended Procedures for Canadian Standards

Canadian Shipbuilders are well aquainted with CSI, Lloyds and IEEE standards. The standards which are under development now are either military or non-marine. They could be used as guidelines for the industry until either new, maritime oriented documents are available, or until unique shipboard sections are written for marine use. It is therefore recommended that;

a. EIA RS-455 to 458 be used as a working standard for system designs once it becomes available and that it be interpreted for shipboard use in accordance with sensible marine electronic engineering practice.

b. The USN standards, when available, be used for shipboard installations and they be interpreted as standards for non-military use.

c. A new Section for TP-127 be prepared. We suggest this must be preceded by both shore and sea trials on typical cables and devices and on a test installation.

d. Transport Canada consider initiatives to address the lack of fibre standards with the appropriate national authorities and classification societies.

6. SHIP SAFETY

6.1 Role of Transport Canada

Ship safety is a primary concern of Transport Canada. To this end Transport Canada maintains technical standards (such as TP 127 Ship Safety Electrical Standards) and inspectors (Canadian Steamship Inspectors) to ensure that ship safety in Canadian waters is of the highest standards.

As with any new technology, fibre optic standards & documents must be established to ensure the high standard of safety is not compromised during the introduction of the technology.

Optical fibres being manufactured from high purity glass provide no fire or spark hazards. However the cabling materials which protect the optic fibre are usually made of petro-chemical plastics and this generates some fire hazard. All fibre optic systems are terminated by an opto-electro connector, where the optical signals are converted into electrical signals. In the electrical/electronics components, all the standard procedures outlined in TP 127 and other documents must be observed.

6.2 Special Attributes of Fibre Optic Cables Related to Ship Safety

This section covers only those attributes of fibre optics which relate to ship safety.

i) Flammability

High purity optical fibres are manufactured from glass and present no fire hazard. Glass on heating beyond 800 C softens, then melts. It will not support combustion. Covering the glass fibre is a thin buffering plastic material made from hytrel, epoxy, nylon, teflon, etc. Although these materials could support combustion the amount used is insignificant . Quoting, Doug Briggs, Corning Glass Company:

" In one kilometer of fibre only 2 oz. of plastic are used for buffering material".

A more serious consideration is the cabling material which protects the glass fibre from mechanical abuse. Standards committees, noting this potential problem have addressed this by establishing a flammability test* for cable and connectors.

*EIA Flammability Test FOTP-7 Connectors, FOTP-77 Fibres.

For ship safety, fibre optic cable must have a high burn resistance or the ability not to support or propagate combustion after a heat source is removed. These requirements would be identical to those for cables as outlined in IEEE-45, 1977.

Recognizing the importance of flame resistant materials, many Manufacturers, (example Pirelli Cable Corp) advertise fibre optic cables using materials which pass the IEEE 383 Flame Test. This test meets the 70,000 BTU requirements of IEEE-45.

ii) Spark Hazard

Fibre optic cables carry light pulses not electrical signals, hence they exhibit no spark hazard. Fibre optic cables can be used in explosive environments with no special precautions.

iii) Electrical Noise

Fibre optic cables being an insulator are completely impervious to electrical or RF noise. They neither pick-up nor generate "electrical" noise. This implies fibre optic cable could be carried next to large current carrying cables with no effect. Optical cables in effect isolate electrical systems, hence ground loops which often plague ship electrical installations do not exist. Many electronic systems, radar and other navigation aids required shielded (R6-58 type) cabling. In long runs, special shielding, triaxialcable, etc. may be required. Fibre optic cables require no special cabling restrictions thus special standards may not be required.

Section 13, TP127, Number 13 states,

"All cables within 9 meters of any receiving antenna system, radio room or radio navigation apparatus, unless a metallic deck or bulkhead intervenes, shall be metal sheathed, metal-braded or otherwise adequately screened, or arranged so as to prevent radiation or reception of interferring spurious signals."

This rule is not necessary for fibre optics cables.

iv) Vibration

All ship cables, connectors and components are subjected to vibration often more severe than any of the other transport sectors. Connectors may come loose, wires short and the vibration can generate electro-maqnetic interference. Optical cables do not suffer from problems of shorts or interference, but mechanical stress on the relatively brittle glass fibres may cause breakage or micro bending losses.

In the case of the cargo vessel "America Maru" particular attention was payed to the vibration. Good design ensured optical fibre transmission lines and hardware were highly resistant to vibration.

One supplier, ITT Cannon Electric,subjects all fibre optic connectors to the dynamic vibration tests, MIL STD-1344A, Method 2005, test condition 11, except that the cycle is performed 4 times in 3 mutually perpendicular directions for a total period of 3 hours at a peak acceleration of 20 g's.

The MIL STD test is recommended for the present.

v) Salt Water Ingress

All marine cabling and connectors are subject to prolonged exposure to high humidity, moisture or salt spray. Salt water is most corrosive on metals especially low conductivity metals. Great precautions are required to ensure electric cables will survive in this environment. Optical fibres are not affected by moisture, water or salt. In practice a thick layer of HYTREL or other moisture impervious material covers the fibre. Doug Briggs of Corning Glass claimed:

"all SDF fibres are water tested and guaranteed with no loss in performance even in a sea soak environment of up to 1 year."

There is one situation where moisture can cause adverse effects in fibre cables. Despite the best efforts of fibre manufacturers, very small micro-cracks exist on the surface of the fibre. These imperfections contribute to the overall light loses. Under tension, these cracks can grow, penetrating into the fibre, further increasing the light losses. Normal cables even under tension can be expected to last 20-50 years. However, if water is present, the process is accelerated and a form of stress induced corrosion can severly reduce the expected cable lifetime. In tow cables for tethered vehicles where the cables are under constant stress, special preventative designs ensure fibre integrity. As an example, the US Navy tow cables place the optical

fibre inside a beryllium metal alloy tube to keep the water out.

This area requires further investigation and study.

6.3 One area of Special Concern

Light, once trapped inside an optical fibre remains there withlow optical losses unless the fibre is bent excessively. This property makes fibre communication links secure and ensures that cross-talk between fibres is non existent. However this property has one negative result, intrinsic optical interference.

When glass is heated up beyond 400 degrees C it radiates light, which is trapped and carried to the optical receivers. This results in a background "noise" level which reduces the optical signal/noise level. In a communication link, at some temperature, the signal/noise level will fall to a value where the links ceases to carry valid data.

In the case of a shipboard fire, the longer the communication system survives, the greater the chance of saving the ship. Preliminary measurements at Dalhousie University, indicate optic fibre data links will out survive copper data links. The background light radiation level increases almost linearly with temperature. Although the insulation burns away the fibre survives and still transmits optical signals at temperatures over 1000 degrees C. We have a verbal report of a fire in a telephone cable vault wherein all conventional circuits were destroyed but the fibre circuits were unaffected.

The data integrity also depends on the method used to encode data and these factors should be investigated.

6.4 Recommendations

Fibre-optic systems consist of both electrical and optical components. The installation and safety procedures as layed down in TP 127 "Ship Safety Electrical Standards" are satisfactory for electrical installations. When augmented by IEEE STD 45-Recommended Pratice for Electric Installation on Ship Board; IEC Publication 92 - Electrical Installations in Ships and classification society regulations, electrical standards are well documented.

Extensive work is underway to produce fibre standards but the areas of flammability,salt water ingress and ice crushing pose special concerns for marine installations in the Canadian environment. Further investigation is required into these properties before fibres can receive a completely clean bill of health.

7. OPPORTUNITIES FOR MARINE INDUSTRY

7.1 New Technology

Fibre optics is a new technology to marine industry. Before fibre optic systems are accepted, there will be many opportunities for consulting, custom engineering and sea trials. Canada has a unique climate with temperatures ranging from -60 to 50 degrees Centigrade. The engineering challenges associate with using a new technology in our climate will be large. In the end, we can claim, if it works in the Canadian climate, it will work anywhere in the world.

7.2 Education and Training of Shipbuilding Community

On several occassions, shipbuilders commented on the need for hands-on training. It is not just a question of installation procedures, but the knowledge that optical fibre is different from copper cable. Little difficulty is expected in pulling fibre cables on ships, but standards are required to ensure fibre properties such as minimum bend radius are observed and these standards must develop before effective training can proceed.

7.3 Safety Testing and Certification

The uniqueness of the Canadian climate and marine transportation will necessitate the writing of new standards for fibre optics. Special attention must be given to bulkhead penetrators, water tight gland seals and ice crush. Optical fibre cable is claimed to withstand temperatures three times that of copper cables. If this is true then optical fibre would provide an extra margin of safety in ship fires. The longer control can be maintained, the greater the chance of putting the fire out. Studies on flammability of optical fibre and date integrity in a high temperature environments are needed.

7.4 Potential Coast Guard Applications

The new polar ice breaker offers a unique test bed for a fibre optic information or implementation of control application. It is always easier to install cable during building than during refit. The expected high electrical noise from thyristor control circuits should verify the insensibility of fibre optics to electrical noise. In addition, the ice breaker will work in the full temperature range and sea states.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

This report has described a situation whereby

a. We are poised at the beginning of a major upswing in the use of fibre cables at sea.
b. There are no non-military shipboard standards in existence.
c. The standards which are forthcoming are not marine oriented.
d. There are some areas of cable performance such as ice crush, flammability and salt water ingress which impact on the marine use of cables.
e. Standards for installations are necessary to ensure not only good installation practice but also guidance for the preparation of training programs.
f. If standards are to be prepared there must be some practical experience and the Coast Guard fleet would seem to offer a test site wherein there is good engineering justification for fibre installations.

8.2 Recommendations

It is recommended that;

a. Transport Canada undertake a program leading to the eventual adoption of standards for fibre cables to parallel those for copper as contained in TP127. This program would consist of,

    i) Shore based trials on fibre cable behavior under conditions of tensions and bending, ice crushing, flammability and salt water ingress.
    ii) Evaluation and/or development of connectors and bulkhead penetrators.
    iii) Sea trials under conditions of high electrical noise levels and high data rates.
    iv) Preparation of draft standards.

b. Transport Canada initiate dialogue with other national authorities and classification societies towards the adoption of international standards by

    i) Maintaining an on-going evaluation of developments in non-marine and military standards,
    ii) Meeting with other national authorities to evolve non-military marine standards.

FIGURES

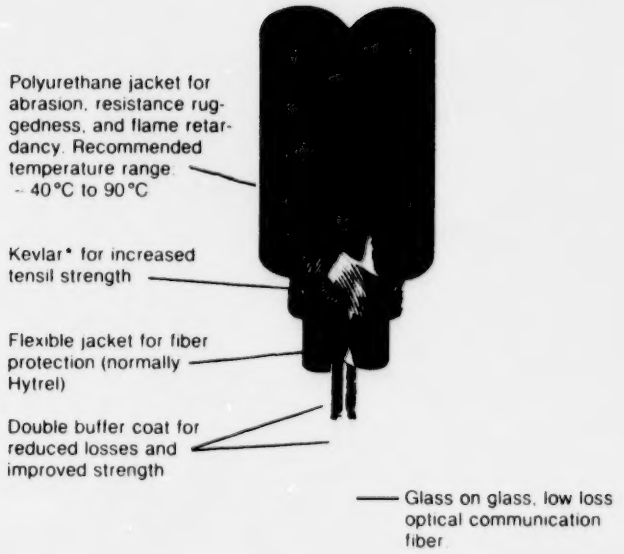
Polyurethane jacket for abrasion, resistance ruggedness, and flame retardancy. Recommended temperature range: - 40°C to 90°C
Kevlar* for increased tensil strength
Flexible jacket for fiber protection (normally Hytrel)
Double buffer coat for reduced losses and improved strength
Glass on glass, low loss optical communication fiber

Fig. 1 **Single channel fibre optic cable shows protective layers over the glass fibre.** (Courtesy of Pirelli).

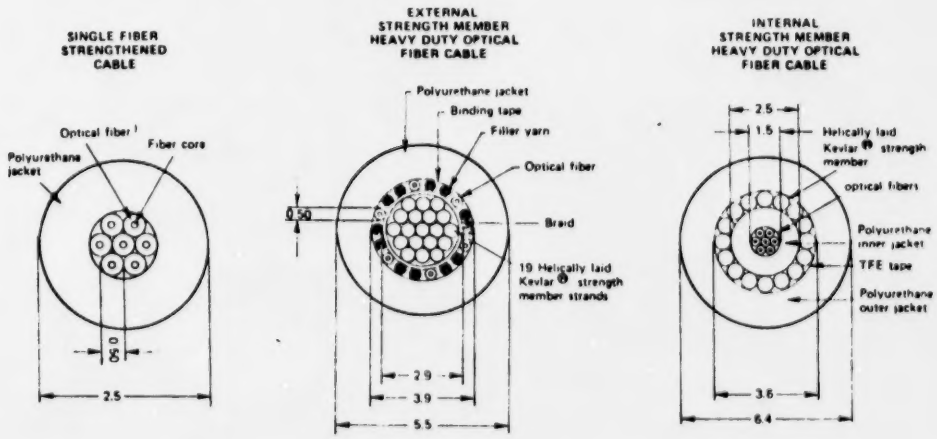

Fig. 2 **Typical multichannel fibre optic communication cables.** (Courtesy of ITT).

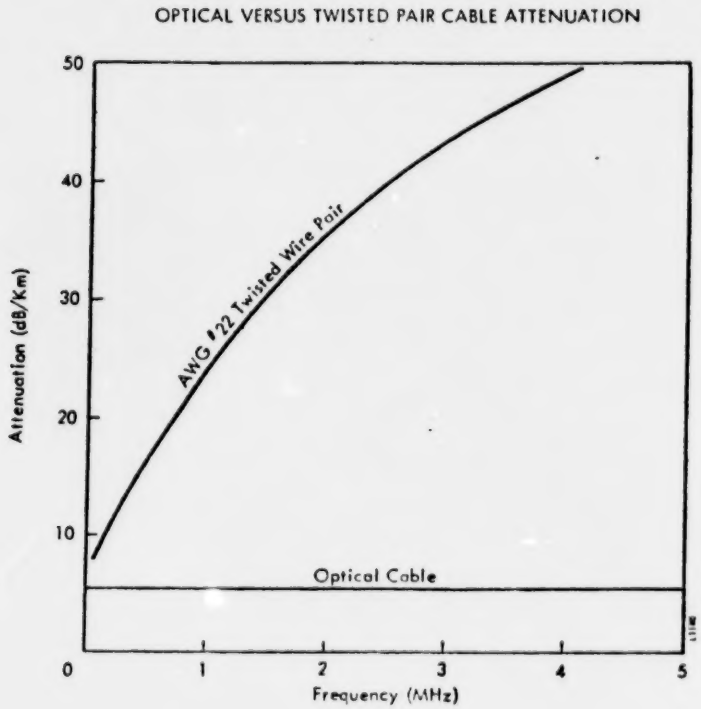

Fig. 3 **Frequency response curves for twisted copper wire pair versus fibre optic cable.** (18)

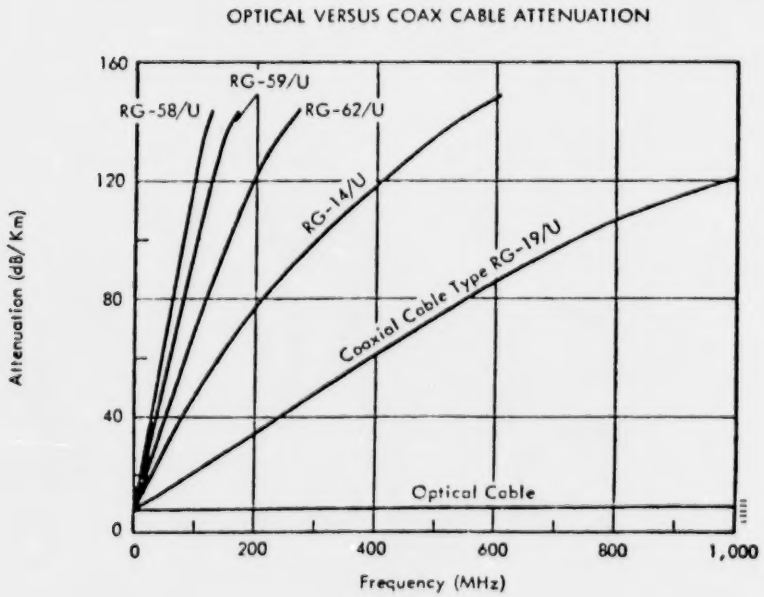

Fig. 4 **Frequency response curves for coaxial cable versus fibre optic cable.** (18)

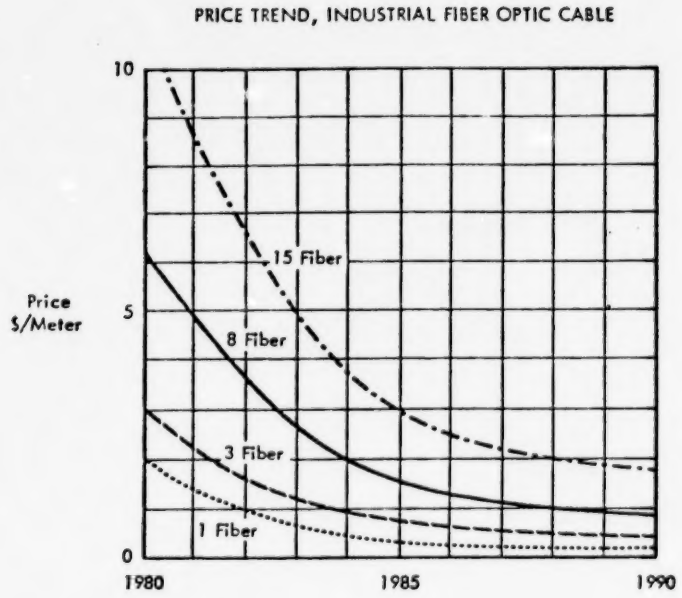

Fig. 5 **Price trends for industrial fibre optic cable.** (18)

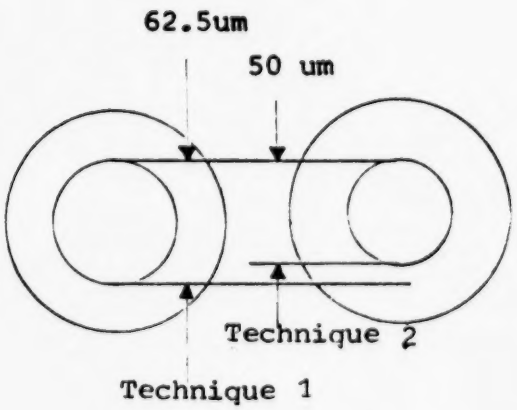

Fig. 6 **Double exposure of lighted fibre optic core shows effect of two different techniques used to measure the core diameter.** (16)

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APPENDIX A

Contacts With Outside Agencies

Michael DiMauro, Rochester Corporation (cable manufacturer)

Stephen Forish, Electronic Industries Association (standards)

Max Reid, Canadian Embassy, Washington, D.C. (information)

J.J. Myette, Pirelli (application to ship radar)

Robert Martinet - Fiber Com (fiber optic components)

Derek Baker, Sperry-Univac Inc. (SHINPADS)

Tom Woolfolk, Sperry Marine (fiber optic components)

Cmdr. L. Magliere, DND, Ottawa (fiber optic SHINPADS)

Bill McCloy, Polar Ice Breaker CCG (applications)

J. Bolok, US Dept. of Navy (Naval Architect)

John Venoit, Canadian Manufacturers Association
(ship suppliers)

Jim Graham, Halifax Industries, Dartmouth slips (cabling)

Malcolm Martype, Ferguson Industries, Pictou (ship cabling)

Bob Thompson, Cable Technology (ocean cable)

Theo Theodossi, Gianni Petro Marine Association, San Diego
(bulkhead penetrator)

Luke Huybrechts, ITT, Roanoke (fiber optics systems)

Bob Kochonski, NOSC, San Diego (standards)

Pat Kelly, Newport News Shipbuilding (cable standards)

Ken Roberts, Simplex Wire & Cable (ocean cables)

Gary McMahon, DREA, Dartmouth (fiber optic systems)

Steve Grossman, M. Rosenblatt & Son (Naval Architects)

Rick Skinner, Evans Yeatman & Endal, Halifax (electric cable)

Ross Kelly, Automatic Industries Inc., Vitro Laboratories
(FO standards)

Don James, CCG, Fleet Ship Systems (electrical cables)

Robert Hoss, Warner-Amex (installation standards)

Doug Briggs, Corning Glass (flammability of fibers)

James Dolan, American Bureau of Shipping

Hiliary Allen, Lloyd's Register of Shipping

Lenny Bloom, Officer of the Navy, US (release of standards)

Donna Collins, DREA Library (standards)

Pat Ingham, DSS (release of DOD report)

Ron Doyle, CANSTAR (SHINPADS, IEC committee)

Ray Johnston, Litton Systems Ltd (ship installation)

Dick Shade, Def[illegible] Electronic Supply Centre (handbooks of FO (handbooks of FO installation)

APPENDIX B

List of Marine Companies Contacted

American Bureau of Shipping
J. Dolan Assit. Chief Surveyor, Operations Division
G. Mason Assit Principal Surveyor for Canada

Lloyds Register of Shipping
H. Allen Chief Representative for USA

Canada Steamships Inspectors
C. LeBlanc

Sperry Univac
D. Baker, Manager Defense Systems Division

David Taylor Naval Ship Research and Development Centre
J. Bolek Engineer/Naval Architect

Scan Marine
Jim Hazeltine

Halifax Industries
Jim Graham

Ferguson Industries Ltd.

Cable Technology, Inc.
Bob Thompson, Vice President

Giannini Petro Marine
T. Theodossi, President

Newport News Shipbuilding & Drydock
Pat Kelly, Cable Engineer

M. Rosenblatt & Son, Inc.
Grossman, Electrical & Electronic Engineering

Evans, Yeatman and Endal (Associates Ltd.)
Rick Skinner, Cable Engineer

Automation Industries, Vitro Laboratories Division
Ross Kelly, Systems Technology Supervisor

Ingalls Shipbuilding
Ray Johnson

Nippon KAIJI KYOKAI, Register of Shipping

Canadian Shipping Association

Appendix C

Summary of MIL-STD-1678 Fibre Optics Test Methods and Instrumentation

This document contains

- list of definitions
- measurement methods and equipment
- test methods and requirements

Test Methods include

1010	Fibre size measurement
1020	Fibre bundle diameter measurement
1030	Number of fibres
1040	Number of transmitting fibres
2010	Cyclic flexing
2020	Low temperature flexibility (cold bend)
2030	Impact testing
2040	Compressive strength
2050	Cable twist
2060	Cable twist-bend
3010	Cable Tensile Load
4010	Power transmission vs temperature
4020	Power transmission vs temperature cycling
4030	Power transmission vs humidity
4040	Tensile loading vs humidity
4050	Freezing water immersion - Ice crush
4060	Dimensional stability
5010	Flammability
6010	Radiant power measurements
6020	Attenuation measurements
6030	Radiation pattern measurement
6040	Acceptance pattern measurement
6050	Pulse spreading
6060	Far-end crosstalk
6070	Fibre (bundle) transfer function
6080	Refractive index profile (Interferometric Method)
6090	Refractive index profile (Near Field Method)
6100	Refractive index profile (Reflection Method)
8010	Insulation blocking, fibre optics cable
8020	Wicking
8030	Fluid immersion
8040	Fibre and bundle end preparation
8070	Jacket flaw detection and leak test

Military Authority responsible for fibre optic components

Subject	Authority
Fibres	Coradcom
Couplers	Navsea
Splice	Navesea
Cable	DOD-C-85045
Cable assemblies	Navsea
Hull penetrators	Navsea
Bulk head penetrators	Navsea & others
Repeaters	Coradcom
Sources	Navelex
Detectors	Navelex
Connectors	Navsea, Navelex
Symbology	EIA
Terms & definition	NTIA
Fabrication	Navair, Navsea, AF
Instrumation	Navair, Navsea, Navsea, AF

APPENDIX D

Electronic Industries Association, RS-455-XX Standards

Title	- XX
Cable Flexing for Fibre Optic Connectors	01
Impact Test Measurements	02
Temperature Cycling (Thermal Shock)	03
Fiber Optic Connector Temperature Life	04
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* Material in study or preparation. Not yet available from EIA.

APPENDIX E

Summary of IEC-46E International Standards

Standards cover the following general areas:

1) Mechanical, electrical and environmental tests, including methods, equipment and procedures.

2) Physical and electrical characteristics of fibre and cable including light and signal transmission characteristics, impurity analytical methods and splicing methods.

3) Connectors and couplers for fibre and cable including physical size, stress and temperature limits, adhesive quality and ratings.

4) Light sources including LEDs and lasers.

5) Photodetectors, electrical and mechanical characteristics including physical size and environmental limitations.

Standards cover the following specific areas:

Optical Fibres

1) General Requirements

2) Measuring Methods
   - dimensional tests
   - mechanical tests
   - transmission and optical characteristics
   - environmental tests for optical fibres

Optical Cables

1) General Requirements

2) Mechanical Tests
   - tesile strength
   - crush
   - import
   - isostatic pressure
   - bending
   - torsion
   - flexing
   - snatch
   - kink

3) Environmental Tests
   - temperature cycling
   - sheath integrity
   - water penetration